National Renewable Energy Laboratory

USA Trough Initiative

Integrated Solar Combined Cycle Systems

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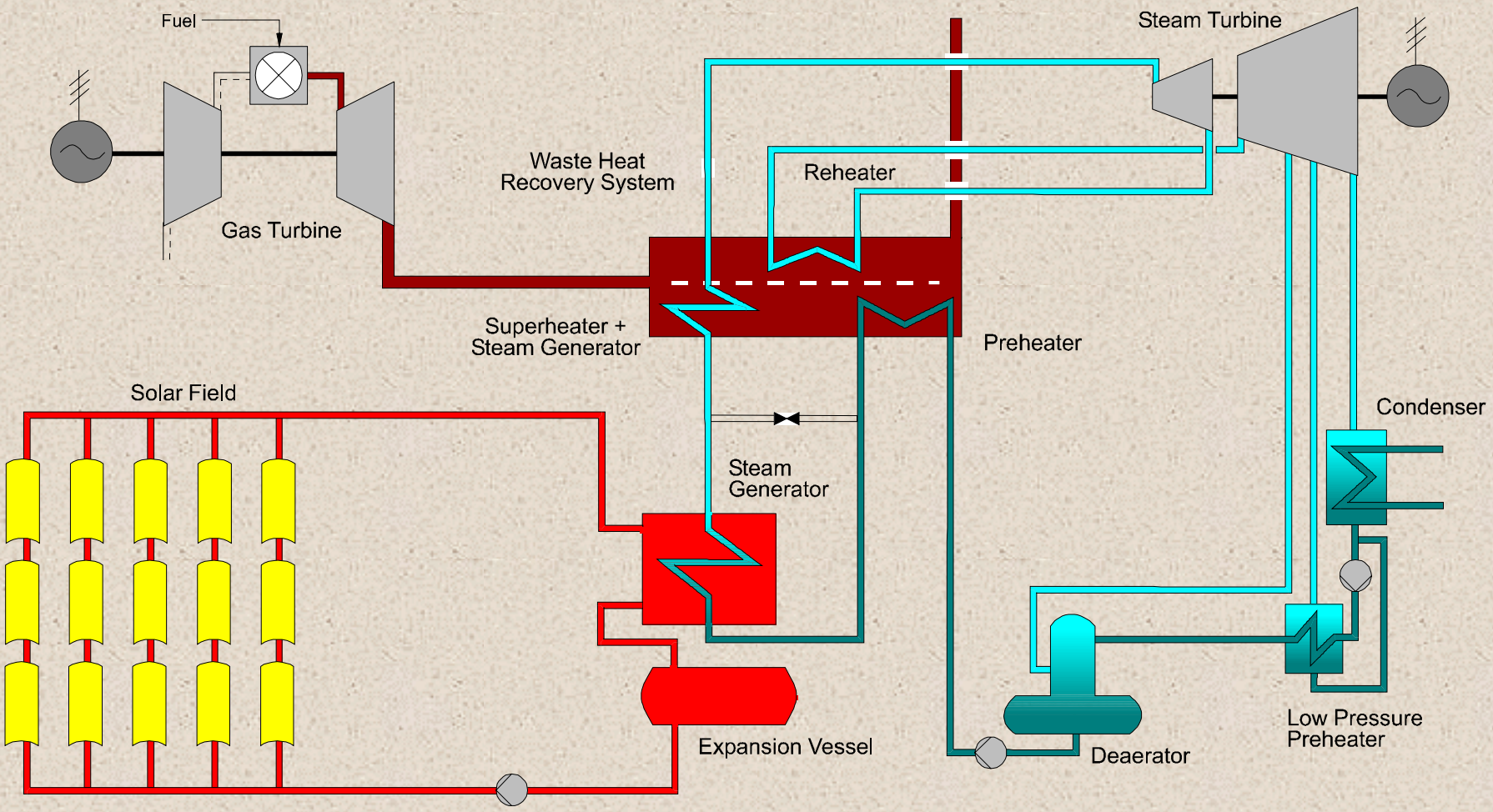
Integrated Solar Combined Cycle System



Thermodynamic and Economic Benefits

- Incremental Rankine cycle efficiencies are 95 to 120 percent those of a SEGS plant, and up to 105 percent those of a combined cycle plant
- Daily steam turbine startup losses are eliminated
- Incremental Rankine cycle power plant costs are 25 to 75 percent those of a SEGS plant

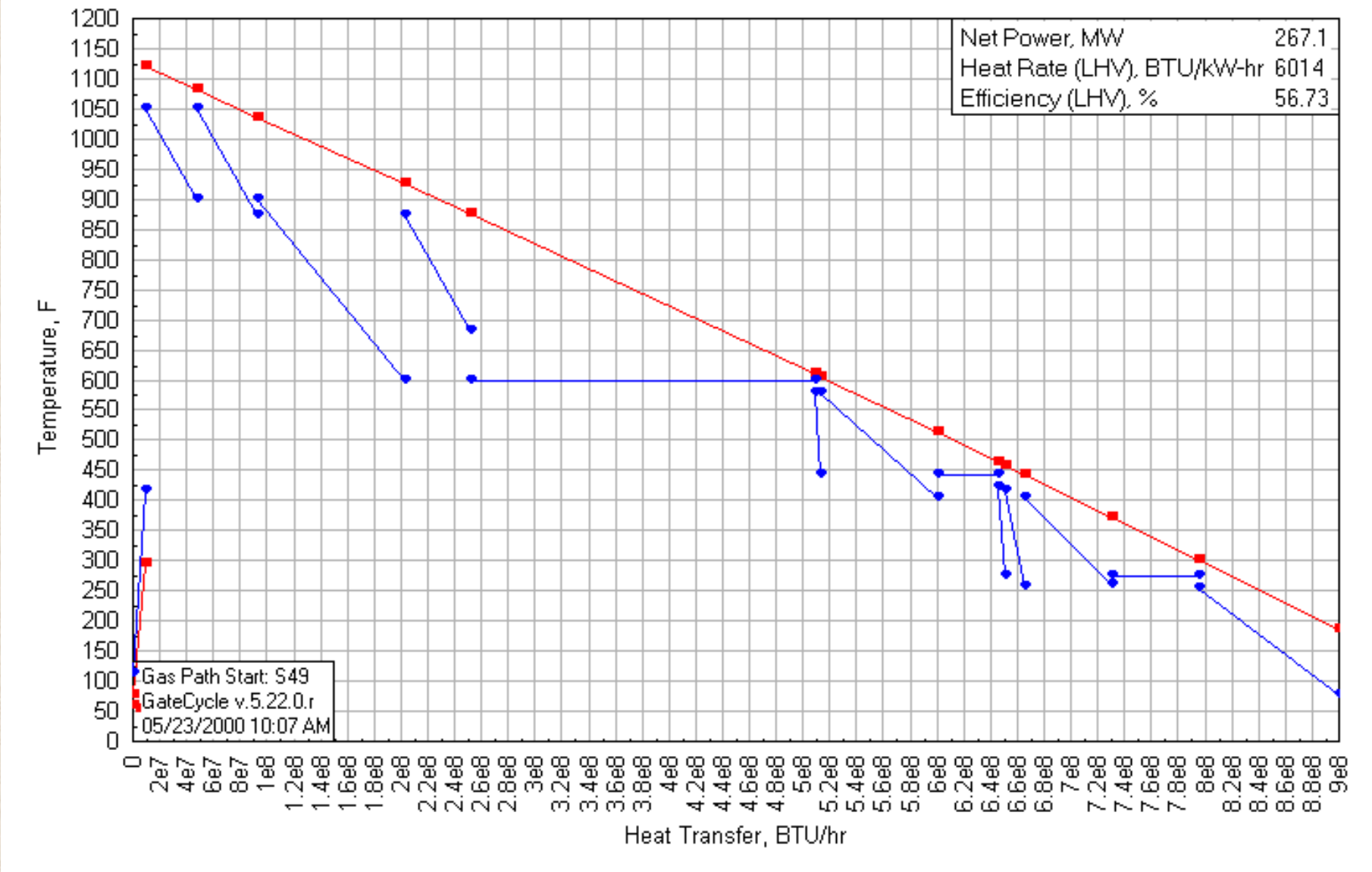
Thermodynamic Benefit

- Solar conversion efficiencies are higher than conventional plants, yet Brayton and Rankine cycle conditions remain unchanged
- Thermodynamic availability is improved by reducing temperature difference in heat transfer
- Largest Rankine cycle temperature differences occur in high pressure evaporator of the heat recovery steam generator

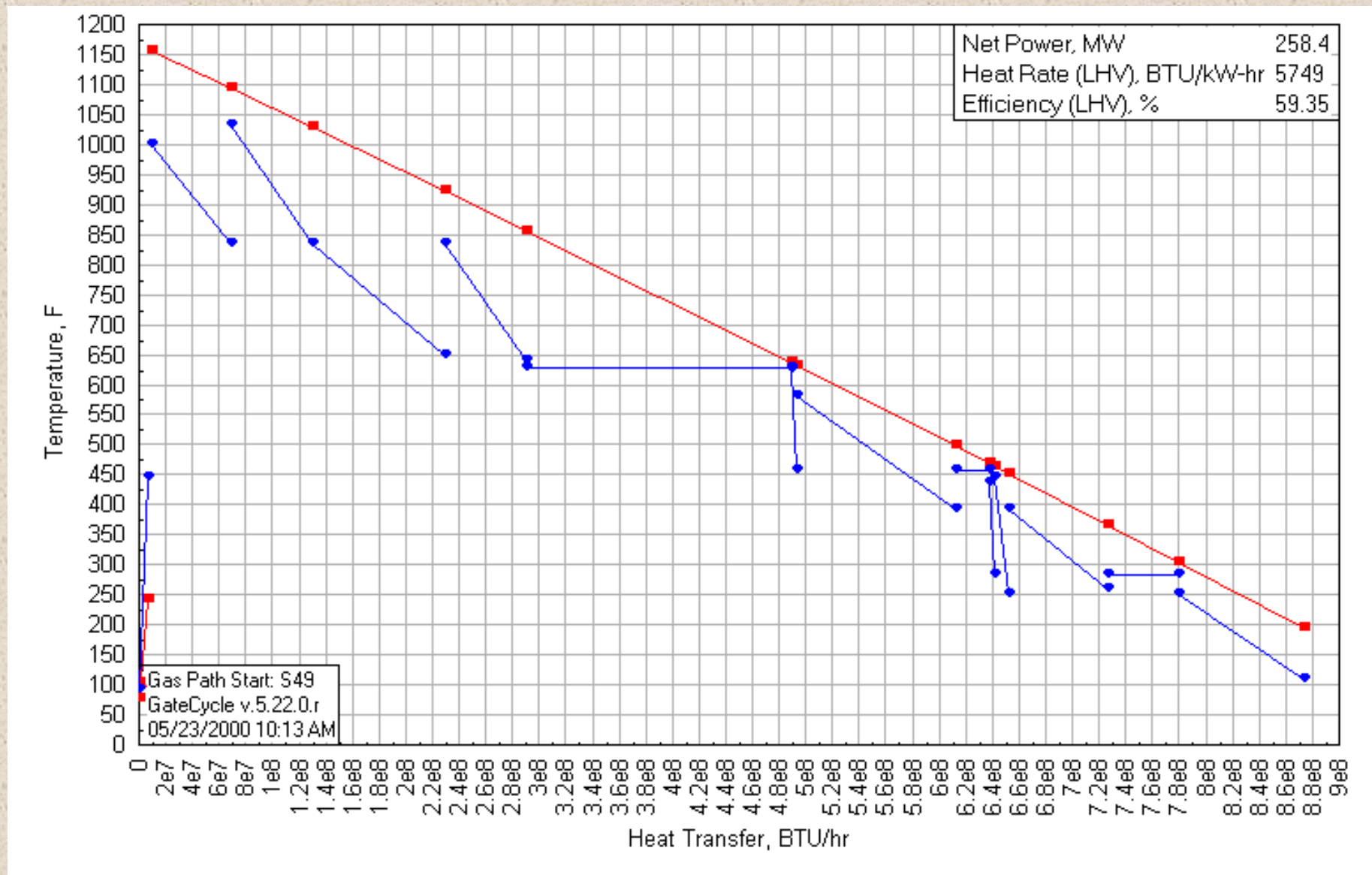
Thermodynamic Benefit

- The most efficient use of solar energy is displacing saturated steam production
- Corollary: Sensible heat transfer has the smallest temperature differences; thus, the least efficient use of solar energy is feedwater preheating and steam superheating

Heat Transfer Diagram for Combined Cycle Plant



ISCCS with Small Solar Input



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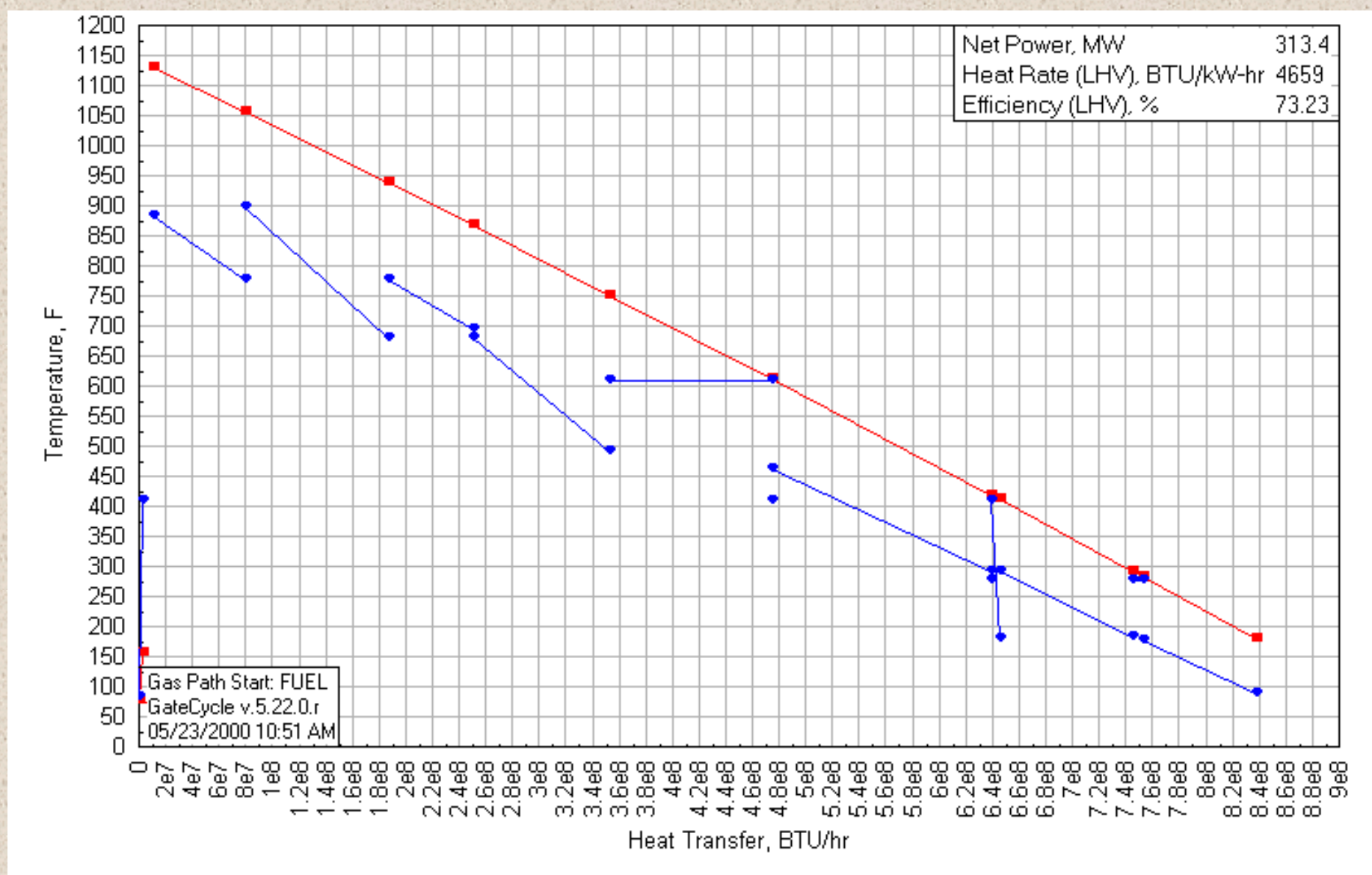
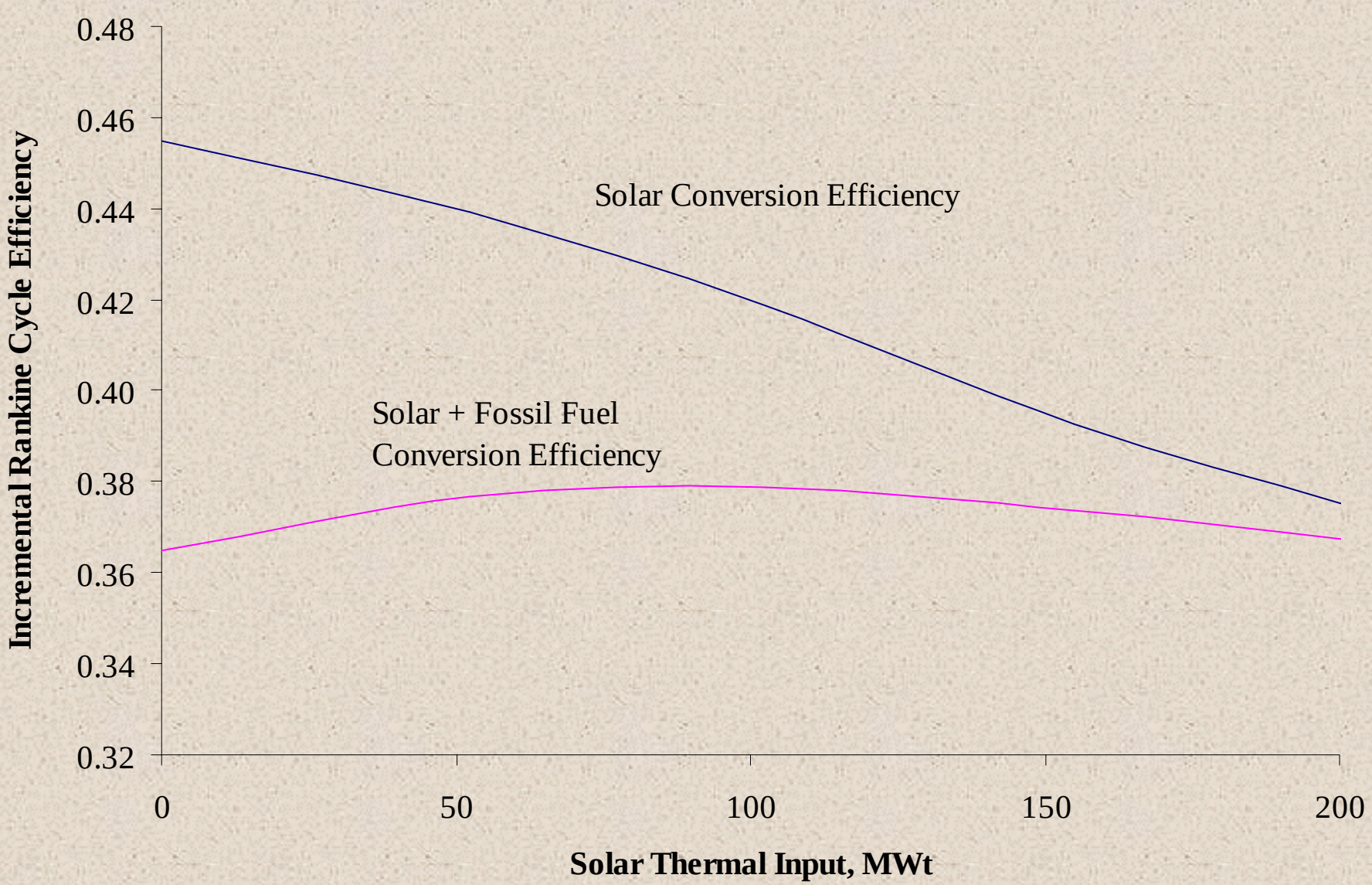


Inherent Limits

- If solar conversion efficiencies are to match or exceed SEGS plants, annual solar contributions are limited to 2 to 7 percent
- Annual contributions above 10 percent can be easily achieved without the use of thermal storage, but net solar-to-electric conversion efficiencies will be below 30 percent

Benefits and Limits



Part Load Rankine Cycle Efficiencies

- Declining conversion efficiency with increasing solar contribution is not due to decrease in turbine efficiency at part load

– Steam flow rates, and therefore pressures, are high during the day, and lower at night

– Throttling introduces a loss in thermodynamic availability; thus, sliding pressure operation is preferred

– Extraction feedwater heaters are not used; thus, the final feedwater temperature is independent of Rankine cycle load

Part Load Rankine Cycle Efficiencies

- Turbine efficiencies (continued)

  – At night, the decay in steam flow rate is matched by a decay in steam pressure

  – Volume flow rate remains almost constant; thus, the turbine blade velocity vectors remain close to design values

- Rankine cycle penalties during majority of operating hours can be very small

Main and Reheat Steam Conditions

- Variable pressure and constant temperature
  - Superheater and reheater sized for solar operation
  - Main and reheat steam attemperation required at night
  - Constant turbine temperatures, but high consumption of feedwater

Main and Reheat Steam Conditions

- Variable pressure and variable temperature
  - Superheater and reheater sized for evening operation
  - Main and reheat steam temperatures decay during solar operation
  - Reasonable low pressure turbine exhaust moisture maintained by reheat steam
  - No feedwater demand for attemperation except following solar steam generator trip

Design Recommendations

- For ‘F series’ gas turbines and 3 pressure heat recovery steam generators, solar thermal inputs should be limited to 100 to 300 percent of high pressure evaporator duty

- Thermal inputs to low pressure evaporator, intermediate pressure evaporator, feedwater preheater, superheater, and reheater are thermodynamically much less efficient

Design Recommendations

- Variable pressure/variable temperature designs offer reasonable efficiencies, less complex operating procedures, reduced water consumption, and improved availability
- To maintain reasonable conversion efficiencies, solar contributions above 10 percent are best provided through the use of thermal storage